Optik 154 (2018) 558–565

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Full length article

A camera calibration method based on plane mirror and vanishing point constraint

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ARTICLE INFO

Article history:
Received 26 July 2017
Accepted 18 October 2017

Keywords:
Machine vision
Parameter calibration
Vanishing point pair
Plane mirror

ABSTRACT

In order to avoid a cumbersome calibration of camera parameters, a method of self-calibration using the imaging features of a plane mirror and the vanishing point pair constraint is proposed. A plane mirror and calibration template were placed at a certain angle and non-vertical geometric constraints were obtained from the calibration template, as well as from the virtual image of the calibration template. So all the internal parameters were calibrated at once. In order to reduce the influence on the calibration parameters of the vanishing point position, the least squares algorithm and the LM algorithm were used to optimize the parameters. Simulations and real experimental results show that the method has a high accuracy and robustness.

1. Introduction

Camera calibration is the process of solving for the model parameters of the camera according to a camera model, which is based on the image information of the feature points and the 3D spatial information. At present, there are many camera calibration methods [1], which can be divided into two types: traditional calibration methods and camera self-calibration methods. A traditional calibration method [2] gets the internal and external parameters under a certain camera model, based on specific experimental conditions, such as the shape and size of the calibration reference, which should be known. It has stricter requirements for its calibration reference and image coordinates. In 1992, Hartley [3] and Faugeras [4] first proposed the idea of camera self-calibration. This method only depends on the corresponding relationship between image and image of the surrounding environment during the movement process of the camera. Many scholars have researched this aspect, among which the vanishing point of orthogonal characteristic calibration method has become a research hotspot.

Caprile [5], as well as Beardsley [6] first proposed a method to calibrate the camera by using the geometric characteristics of the vanishing points. Wang [7] uses three sets of lines and vanishing points to realize the camera calibration, but the method requires that these three sets of line segments be the same length as well as being mutually perpendicular in the calibration space; these calibration conditions are quite harsh. Chen et al. [8] calibrate the parameters using 4 vanishing points produced by a square to establish the vanishing line constraint equation, which is more sensitive to noise due to the need to solve the Kruppa equation. Huo [9] generates a pair of orthogonal vanishing points using two pairs of orthogonal parallel lines, and establishes the constraint equations with a relationship to the origin of the camera. There are other calibration methods using the orthogonal vanishing point [10–12] generated by rectangular, cylindrical, or a cube (long).

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https://doi.org/10.1016/j.ijleo.2017.10.086
0030-4026/

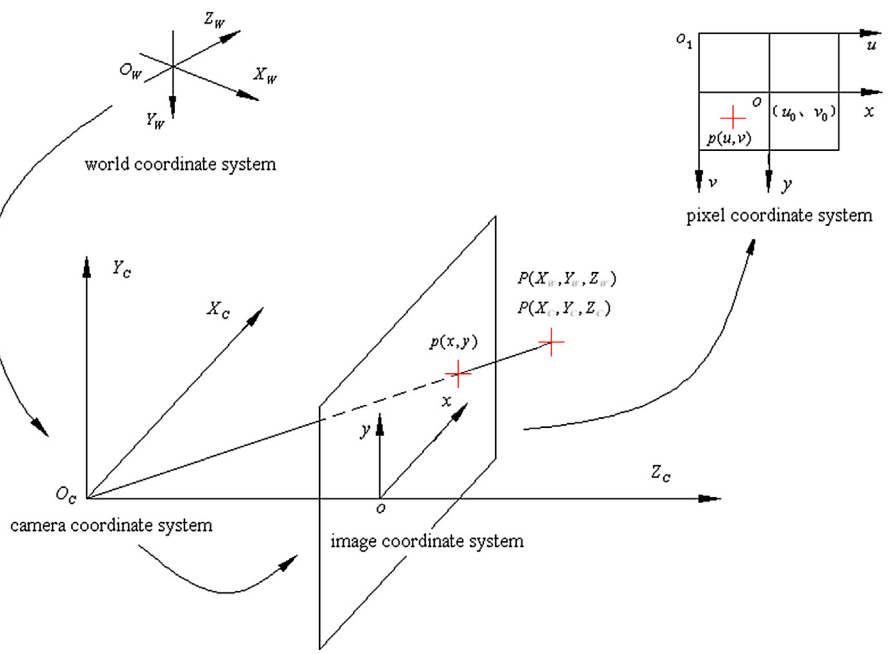

Fig. 1. Relationship among camera coordinate systems.

As at least three images need to be taken in different positions to calibrate the camera parameters, it is quite cumbersome, whether moving the camera or moving the calibration template.

In order to avoid the disadvantages of the traditional calibration method, a new calibration method is proposed based on the idea that the constraint equation can be used to obtain the intrinsic parameters of the intrinsic camera [13–16]. This method uses the principle of mirror reflection [17,18], puts the calibration template and plane mirror non-vertically, they only need to be located once, and there is just one shot: all parameters can be calibrated without moving the camera or the mirror.

2. Camera calibration model

According to the pinhole model [19], as shown in Fig. 1, the mapping relationship of spatial coordinates $P(X_W, Y_W, Z_W)$ and pixel coordinates $p(u, v)$in the image coordinate system is

$$\lambda \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} 1/d_x & 0 & u_0 \\ 0 & 1/d_y & v_0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} f & 0 & 0 \\ 0 & f & 0 \\ 0 & 0 & 1 \end{bmatrix} \left(\begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} \begin{bmatrix} X_W \\ Y_W \\ Z_W \end{bmatrix} + \begin{bmatrix} t_1 \\ t_2 \\ t_3 \end{bmatrix} \right) = A[\quad R \quad | \quad T \quad]P_W \tag{1}$$

where (u_0, v_0) are the coordinates of the image centre, $f/d_x, f/d_y$ are separately normalized focal lengths; $A = [f/d_x\ 0\ u_0;\ 0\ f/d_y\ v_0;\ 0\ 0\ 1]$ are the intrinsic parameters of the camera; R is a rotation matrix, and T is a translation vector, which forms the external parameters of the camera.

This formula describes the transformation of a point in space from the world coordinate system to the camera coordinate system, then to the image plane coordinate system, and then to the pixel coordinate system.

3. Calibration principle based on plane mirror and orthogonal vanishing point

3.1. Properties of orthogonal vanishing point

In Euclidean space two parallel lines will intersect at infinity, without considering the distortion of the pinhole camera model: according to the theory of projective transformations, the two parallel lines projected to the imaging plane will intersect at one point, which is called the vanishing point – it is the projection of the point at infinity to the imaging plane. According to [20], the line connecting the camera's optical centre and the vanishing point formed in the projection surface by the spatial parallel lines will be parallel to the spatial parallel lines (Fig. 2).

For a square *ABCD* in space, the image in the imaging plane is a quadrilateral *abcd*. According to the principle of the vanishing point, the image of the parallel sides *ab* and *cd* intersect at the vanishing pointv_1, while *bc* and *ad* intersect at the vanishing point v_2. Then $ov_1 \parallel AB \parallel CD$ and $ov_2 \parallel AD \parallel BC$, as $AB \perp AD$, and so $ov_1 \perp ov_2$. Here, v_1 and v_2 are a pair of orthogonal